ANL-07/10 VOL 1

Poland Becoming a Member of the Global Nuclear Energy Partnership

Volume 1 – Summary

Decision and Information Sciences Division

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Poland Becoming a Member of the Global Nuclear Energy Partnership

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by
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PREFACE

As part of President Bush's Advanced Energy Initiative, the Global Nuclear Energy Partnership (GNEP) seeks to develop worldwide consensus on enabling expanded use of economical, carbon-free nuclear energy to meet the growing electricity demand. This will use a nuclear fuel cycle that enhances energy security, while promoting non-proliferation. It would achieve its goal by having nations with secure, advanced nuclear capabilities provide fuel services — fresh fuel and recovery of used fuel — to other nations that agree to employ nuclear energy for power generation purposes only. The closed fuel cycle model envisioned by this partnership requires development and deployment of technologies that enable recycling and consumption of long-lived radioactive waste. In 2006, the Department of Energy (DOE) requested Argonne National Laboratory and its educational partners to perform an economic study regarding Poland becoming a potential GNEP partner. Poland represents a class of countries that presently have no installed nuclear power plants. This work was supported by the U.S. Department of Energy, Assistant Secretary for Nuclear Energy, Science, and Technology, under contract DE-AC02-06CH11357. Volume I summarizes the results of this study. Volume II is a detailed appendix that describes the methodology, assumptions, and results of the economic models that were used for the study.

ACKNOWLEDGEMENTS

Many people have made generous and valuable contributions to this study. Deserving special mention are Professors Marcin Peski, Roger Myerson, and Allen Sanderson of the Economics Department at the University of Chicago, who provided insightful comments and suggested improvements to this study. Two doctoral economics candidates of Professor Rob Porter at the Kellogg School at Northwestern University, Jesse DeLille and Ben Handel, were part of the study team. Special thanks go to Jesse and Ben for their analysis, dedication, and for their creativity in addressing Poland’s macroeconomic and public policy issues. Matt Crozat and Vic Reis of DOE provided very timely and useful assistance. In addition, James Malone, Vice President, Nuclear Fuels, Exelon Corporation, provided helpful comments on the final draft. And lastly, the authors wish to acknowledge the many contributions made by Polish experts and analysts during the study team’s visit to Warsaw. The insights and information provided by them were critical to our modeling and analysis efforts. Their support is gratefully acknowledged.

NOTATION

The following is a list of the abbreviations, acronyms, and units of measure used in this document. (Some acronyms and abbreviations used only in tables may be defined only in those tables.)

GENERAL ACRONYMS, ABBREVIATIONS, AND UNITS OF MEASURE

AFBC	Atmospheric fluidized bed combustion
CEE	Central and Eastern Europe
CO_2	Carbon dioxide
DOE	U.S. Department of Energy
EBRD	European Bank for Reconstruction and Development
EMA	Electricity Market Agency
EMCAS	Electricity Market Complex Adaptive System
EPR	European Pressurized Water Reactor
ESA	Euratom Supply Agency
EU	European Union
GHG	Greenhouse gas
GNEP	Global Nuclear Energy Partnership
IAEA	International Atomic Energy Agency
IGCC	Integrated Gasification Combined Cycle
kgHM	Kilograms of heavy metal
kWh	Kilowatt hour
LCOE	Levelized cost of electricity
LMP	Locational marginal price
MMBtu	Million British Thermal Units
MW	Megawatt
MWe	Megawatt electric
MWh	Megawatt hour

NAEA	National Atomic Energy Agency
NGCC	Natural Gas Combined Cycle
O&M	Operation and Maintenance
PFBC	Pressurized Fluidized Bed Combustion
PSE	Polskie Sieci Eectroenergetyczne (Polish Power Grid Company)
R&D	Research and Development
VVER	Russian type of pressurized water reactor
WASP	Wien Automatic System Planning Package

POLAND BECOMING A MEMBER OF THE GLOBAL NUCLEAR ENERGY PARTNERSHIP

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ABSTRACT

Within a constrained carbon environment, the risks of future natural gas supply, and the need to move to market-based electricity prices, the study team found: (1) the deployment of new nuclear energy in Poland itself is very competitive in the next decade or two; (2) if such generation could be made available to Poland prior to deployment of its own nuclear generation facilities, Poland would benefit from partnering with its Baltic neighbors to import electricity derived from new nuclear generation facilities sited in Lithuania; and (3) Poland appears to be a good candidate for a partnership in the Global Nuclear Energy Partnership (GNEP) as an emerging nuclear energy country.

EXECUTIVE SUMMARY

BACKGROUND

Development of carbon policies and the availability and price of natural gas will affect the competitiveness of nuclear energy in Poland. This concern is shared by the rest of the countries in Central and Eastern Europe (CEE), particularly in the Baltic region. These countries have noted that Russia already has doubled the price of natural gas to the former Soviet republics.[1]

STUDY FINDINGS

Given a constrained carbon environment, the risks of future natural gas supplies, and the need to move to market-based electricity prices, the study found the following: (1) the deployment of new nuclear energy in Poland itself is very competitive in the next decade or two; (2) based on the results of the economic models, the initial plants will be competitive as early as the 2017 time

[1] The international press is reporting that Poland is making two moves to reduce its reliance on Russian energy supplies for its electricity needs: (1) Poland's state-owned electricity company, Polskie Sieci Elektroenergetyczne (PSE), will sign a deal with Lithuania's Lietuvos Energija to link power grids; and (2) Polish Prime Minister Jaroslaw Kaczynski would like (a) a 25% ownership stake in any new nuclear capacity that is built in Lithuania, (b) to share that investment with its three other Baltic partners (Lithuania, Estonia, and Latvia), and (c) to accelerate the schedule to have such capacity available by 2015.

frame, about four years earlier than the official Government timetable for new deployments within Poland; (3) nuclear energy's share of the Polish electricity market could grow to as much as 40%; (4) as a first priority, the early plants should be sited in the northern sector of Poland, in the vicinity of Gdańsk, to address electricity shortfalls in that region; and (5) Poland would also benefit from diversity of electricity supply strategies, including the flexibility of importing electricity from Lithuania.[2]

The four main economic drivers benefiting nuclear energy in Poland are:

- The ~15% increase in the cost of coal-fired electricity as a result of implementation of the Kyoto Protocol;
- The need to hedge any reliance on gas-fired electricity in light of the future supply and pricing policy of Poland's major supplier, Gazprom;
- The need for Poland to complete the transition to a market economy over the next decade to meet the conditions of its membership in the European Union (EU); and
- The eligibility of nuclear power plant projects for concession loans (7% discount rate) from the European Bank for Reconstruction and Development because of the environmental, national security, and economic benefits of nuclear energy.

Poland appears to have significant potential to be a partner in GNEP as an emerging nuclear energy country. It appears that nuclear fuel leasing would be the best fuel supply and disposition alternative — this was Poland's arrangement of choice with MINATOM (Ministry of Atomic Energy of the former Soviet Union) when new nuclear energy was considered in the 1980s.

Within the EU, all investment activities in the energy sector must be reviewed as part of a formal public acceptance process. Poland's National Atomic Energy Agency has already conducted polling and has found increasing public acceptance. Polish authorities have stated that this public polling process will be completed within five years.

APPLICATION OF THIS STUDY TO OTHER COUNTRIES

The likelihood that other CEE countries that are members of the EU will be GNEP partners is equally high because of concerns about their natural gas supply situations and their need to move to a carbon-constrained economy. Such an arrangement, in the short term, could be implemented most expeditiously as a multinational nuclear energy project among the CEE countries, similar to the trans-Baltic project that is now under active consideration.

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[2] If the power bridge connection between Lithuania and Poland were available as early as 2015 and about 350 MWe were imported, Poland could utilize this additional capacity in this period to meet its projected demand needs.

The potential to deploy future nuclear plants and become a GNEP partner may also be significant for non-CEE countries, specifically, developing countries in Asia, Africa, and South America. As these countries improve their standards of living, their needs to diversify their supplies of energy will increase, and, due to likely financial constraints, the interest to develop a regional approach to nuclear deployment will grow as well.

FINDINGS

BACKGROUND

The U.S. Department of Energy (DOE) requested Argonne National Laboratory to analyze the potential of Poland being a member of GNEP. At present, DOE has underway three analyses covering "three very different potential nuclear consumer countries as GNEP partners:" (1) Poland, which currently has no installed nuclear power plant capacity; (2) a second country that has significant dependency on nuclear energy and plans for more deployments; and (3) a third country that has limited nuclear energy capacity and could relinquish its fuel enrichment capabilities. Argonne, partnering with students and faculty at the University of Chicago and Northwestern University, performed both scoping analysis and detailed modeling of the prospects of nuclear energy to serve the electricity requirements in Poland during the next several decades. This modeling provided detailed information on timing, size, and the potential region in Poland where new nuclear energy would have the largest benefits. Argonne and its partners also reviewed the societal and policy issues impacting Poland's role as an emerging nuclear energy country. An emerging nuclear energy country would be dependent on nuclear fuel supply and disposition services from nuclear supplier countries.

Poland's Existing Dependence on Coal

Poland depends heavily on its indigenous supply of coal and lignite for fuel to generate electricity (Figure 1).

As a signer of the Kyoto Protocol, Poland has made the commitment by 2008–2012 to reduce its emissions of the three main greenhouse gases (GHGs) by 6% below the base year of 1998. For many countries, such as the European Union (EU) member states, this corresponds to some 15% below their expected GHG emissions in 2008 and for Annex II countries, a 10% reduction is required). These environmental constraints will have a major deleterious impact on deploying new coal-fired electricity in Poland, which does not sequester carbon.

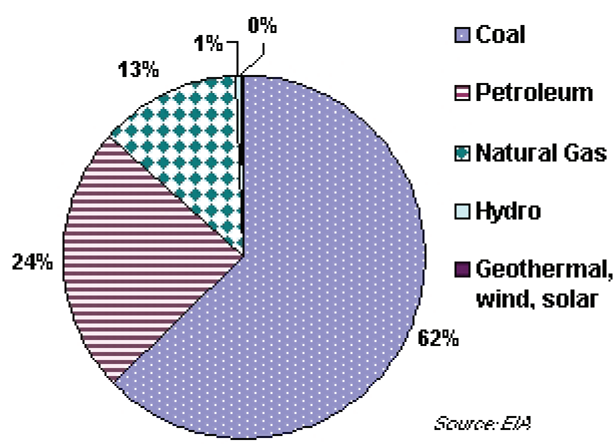

FIGURE 1 Poland Fuel Share of Energy Consumption (Quadrillion Btu) as of 2001

Therefore, to replace or expand its baseload capacity, Poland would need to consider the following alternatives:

Significant Carbon Constraints:

- Integrated Gasification Combined Cycle (IGCC)
- Natural Gas Combined Cycle (NGCC)
- Nuclear Energy

Moderate Carbon Constraints:

- Atmospheric Fluidized Bed Combustion (AFBC)[3]
- Pressurized Fluidized Bed Combustion (PFBC)[4]

Energy Policy

The transformation of the energy sector in Poland is an ongoing process in terms of its restructuring, privatization, and deregulation. The relevant state priorities are:

- EU integration;
- Environmental considerations aimed at decreasing air pollutant emissions;
- Fulfillment of international obligations; and
- Reducing Poland's dependence on foreign imports of oil and natural gas.

The Government's energy policy historically has been laid down in the **Guidelines for Poland's Energy Policy until the year 2020**, adopted by the Council of Ministers in February 2000. The document formulated the strategic directions of the country's activities, the central element of which includes "…promotion of modern, highly efficient power generators and equipment capable of competing both in national and foreign markets." The rationalization policy consists of:

- Improvement of fuel consumption efficiency, i.e., cogeneration promotion;

[3] The higher thermal efficiencies of AFBC systems result in lower coal requirements when compared to current conventional pulverized coal steam plants. This results in lower emissions of greenhouse gases.

[4] PFBC systems can achieve higher thermal efficiencies than AFBC systems. The increased energy in the high pressure gases exiting the PFBC boiler can drive both a gas and steam turbine, known as a combined cycle system. Also, the higher thermal efficiencies of PFBC systems result in lower coal requirements when compared to current conventional pulverized coal steam plants. This also results in lower emissions of greenhouse gases.

- Rational heat and electricity consumption; and
- Promotion of non-conventional and renewable energy sources.

The Government has focused on three areas to promote Poland’s electricity strategy:

- Direct regulations (standards),
- Market stimulation (economic and fiscal), and
- Supporting instruments (information, education, R&D).

At the beginning of 2002, an **Assessment of Implementation and Amendment to the Guidelines for Energy Policy of Poland until 2020** was approved by the Council of Ministers, containing, in particular, a new short-term forecast for the development of Poland’s economy, the fuel and energy sector, until 2005.

Recent Pronouncements by the Current Government Impacting the Deployment of Nuclear Energy

During the course of the study, the Minister of the Polish Economy informed the Assistant Secretary of Nuclear Energy that Poland is planning to introduce new nuclear energy in the 2021 time frame. It would take about 15 years to finish the public review, investment, and construction process. This assessment was supported by a recent assessment done by Poland’s Energy Market Agency (EMA).

After the study was completed, Poland’s Government has been reported to support importing nuclear generated electricity from Lithuania. Lithuania, in collaboration with other Baltic countries, is considering building up to 3,200 megawatt electric (MWe) of new nuclear capacity. The international press has reported that, in December 2006, in a move to reduce Poland’s reliance on Russian energy supplies for its electricity needs: (1) Poland’s state-owned electricity company, Polskie Sieci Elektroenergetyczne (PSE), will sign a deal with Lithuania’s Lietuvos Energija to link power grids; and (2) Polish Prime Minister Jaroslaw Kaczynski would like to (a) import about 350 MWe of nuclear energy using this power bridge, (b) share that investment with its three other Baltic partners (Lithuania, Estonia, and Latvia), and (c) accelerate the schedule to have such capacity available by 2015.

The study included an analysis of importing electricity from Lithuania as an alternative to siting new nuclear plants within Poland. This alternative was considered because of the strong interest exhibited by the PSE and Poland’s National Atomic Energy Agency (NAEA) for a trans-Baltic project.

FINDINGS OF THE STUDY

Results of the Simplified Models

The first set of models was used to assess the basic economic competitiveness of different generating technologies.

1. Screening Analysis

This approach determines the generation costs as a function of the unit capacity factor. For the purpose of this analysis, the European Pressurized Water Reactor (EPR) was chosen as the candidate nuclear energy technology because of its level of interest in the EU.[5] The results of the initial screening analysis show that the EPR unit is economically competitive for capacity factors of 80% or higher and a discount rate of 5% as compared with all fossil-based candidate technologies.[6] This comparison was based on 2003 fuel prices.[7] If a $15/ton CO_2 emission allowance cost is borne by the fossil-based candidates, the EPR unit is economically competitive for capacity factors of 55% or higher at the same discount rate. Assuming 2021 fuel prices[8] and the $15/ton CO_2 cost, the EPR unit is economically competitive for a 40% or higher capacity factor at the same discount rate.

2. Pre-Tax Levelized Cost of Electricity (LCOE) Analysis

The study team developed a simplified model for determining four of the components (i.e., annualized capital costs, fixed O&M costs, variable O&M costs, and fuel costs) for a detailed pre-tax Levelized Cost of Electricity (LCOE) calculation.[9] It did not consider such items as the tax treatment of interest payments, depreciation, and other accrual expenses. The 2015 time frame was used for the financial analysis to support a potential 2021 in-service date. The results of the pre-tax LCOE analysis were calculated based on three discount rates, which are shown in Table 1.

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[5] The EPR was selected as the candidate nuclear plant because of the interest in that design in the European Union. (e.g., a 1500 MW unit is currently being built at the Olkiluoto site in Finland) and being considered actively in Italy and other EU countries.

[6] Usually the capital-intensive technologies, such as nuclear energy technology, are the most economical at high utilization levels.

[7] The nuclear fuel costs typically represent 12–15% of the total cost of electricity produced by nuclear plants. Since uranium ore has to be processed and enriched in order to be used as nuclear fuel, the cost of uranium typically accounts for only a small fraction of the total cost of producing electricity from nuclear power plants. Therefore, even a large increase in the uranium price has a relatively small effect on the nuclear electricity production costs.

[8] According to the Polish Energy Market Agency (EMA) analysis, 2021 is the anticipated in-service date for first nuclear plants in Poland.

[9] See Appendix 4 for detailed explanation of the methodology used to calculate the LCOE for base load power.

TABLE 1 Pre-Tax LCOE Based on 2015 Fuel Prices (in constant 2003 US $/MWh)

	EPR	PC	IGCC	PFBC	PC	AFBC	NGCC[10]
Discount Rate (%)	Nuclear (1500 MW)	Coal (400 MW)	Coal (300 MW)	Coal (150 MW)	Lignite (500 MW)	Lignite (150 MW)	Nat. Gas (300 MW)
5	29.74	31.40	37.89	34.41	31.49	29.32	37.21
8	37.04	35.69	43.65	39.28	36.34	33.48	39.04
10	42.29	38.77	47.80	42.78	39.82	36.48	40.08

The main impact of fuel prices in 2015 is seen on the levelized cost of the natural gas combined cycle (NGCC) candidate, which is relatively high because of a modest escalation of natural gas prices. For a 5% discount rate, the EPR nuclear and AFBC lignite-fired candidate technologies are the lowest-cost options, with levelized costs of $29.74/MWh and $29.32/MWh, respectively. The nuclear candidate is sensitive to higher discount rate values; its LCOE increases to $42.29/MWh at a 10% discount rate. The LCOEs of integrated gasification combined cycle (IGCC) and pressurized fluidized bed combustion (PFBC) candidates are the highest-cost options for all three discount rates.

If the CO_2 emission allowance costs are taken into account, the competitiveness of the EPR nuclear technology improves markedly. The EPR becomes the preferred choice for even a relatively high 10% discount rate. The results of the pre-tax LCOE analysis are shown in Table 2 for CO_2 costs at $10/ton and in Table 3 for CO_2 costs at $15/ton.

TABLE 2 Pre-Tax LCOE Based on 2015 Fuel Prices and CO_2 Cost of $10/ton[11] (in constant 2003 US $/MWh)

	EPR	PC	IGCC	PFBC	PC	AFBC	NGCC
Discount Rate (%)	Nuclear (1500 MW)	Coal (400 MW)	Coal (300 MW)	Coal (150 MW)	Lignite (500 MW)	Lignite (150 MW)	Nat. Gas (300 MW)
5	29.74	38.32	44.50	41.33	41.85	39.63	40.69
8	37.04	42.61	50.26	46.20	46.70	43.79	42.52
10	42.29	45.69	54.41	49.70	50.18	46.79	43.56

[10] The study team used the 2005 World Energy Outlook to determine the projected price of natural gas; it is expected to rise to $5.20–5.60 per million British Thermal Units (MMBtu) in the 2020–2030 time frame (or about 25% above the current prices); if geopolitical tensions rise between Russia and its Central and Eastern European customers, natural gas prices could rise more significantly, such prices for natural gas would make NGCCs economically uncompetitive.

[11] The LCOE analysis included three scenarios for carbon: no tax, a $10/ton charge, and a $15/ton charge.

TABLE 3 Pre-Tax LCOE Based on 2015 Fuel Prices and CO_2 Cost of $15/ton[12] (in constant 2003 US $/MWh)

	EPR	PC	IGCC	PFBC	PC	AFBC	NGCC
Discount Rate (%)	Nuclear (1500 MW)	Coal (400 MW)	Coal (300 MW)	Coal (150 MW)	Lignite (500 MW)	Lignite (150 MW)	Nat. Gas (300 MW)
5	29.74	41.78	47.81	44.79	47.03	44.79	42.43
8	37.04	46.07	53.57	49.66	51.88	48.95	44.26
10	42.29	49.15	57.72	53.16	55.36	51.95	45.30

Both the screening and simplified financial levelized cost analyses demonstrate that new nuclear energy, using proven technology and with moderately escalating fuel prices and potential carbon taxes, would be economically competitive in Poland.

Results of the Advanced Models

The objective of Argonne's grid analysis was to evaluate a candidate nuclear unit within the system in which it will operate. The objective was to ascertain appropriate sizing, timing, and location requirements. This analysis was carried out using the Wien Automatic System Planning Package (WASP) and the Electricity Market Complex Adaptive System (EMCAS) computer models to simulate both the present and future operation of the Polish electric power system in an interconnected and restructured environment.[13] The study team used a 7% discount rate (based on published concession rates and the assumption that a moderate risk profile will exist in the financial markets at the time of deployment of new energy technology in Poland over the next decade or two), a $10/ton carbon price (based on implementation of Annex I of the Kyoto Protocol), and the EPR nuclear plant capacity of 1,500 MWe (note: an additional case was run for 1,000 MWe). This grid analysis utilized as inputs:

- The existing system capacity,
- System reliability requirements,
- Dispatch factors for generating units (e.g., minimum load and spinning reserve requirements), and
- Dynamic factors changing over plant's lifetime (e.g., load growth and economic trends).

[12] The LCOE analysis included three scenarios for carbon: no tax, a $10/ton charge, and a $15/ton charge.

[13] The models evaluate different technologies based on economics. Manpower and other infrastructure requirements needed to implement the least-cost expansion plan are assumed to be analyzed in subsequent studies.

1. Projected Electricity Supply and Demand

The analysis used EMA official projections of electricity consumption and load forecasts, shown in Figures 2 and 3.[14]

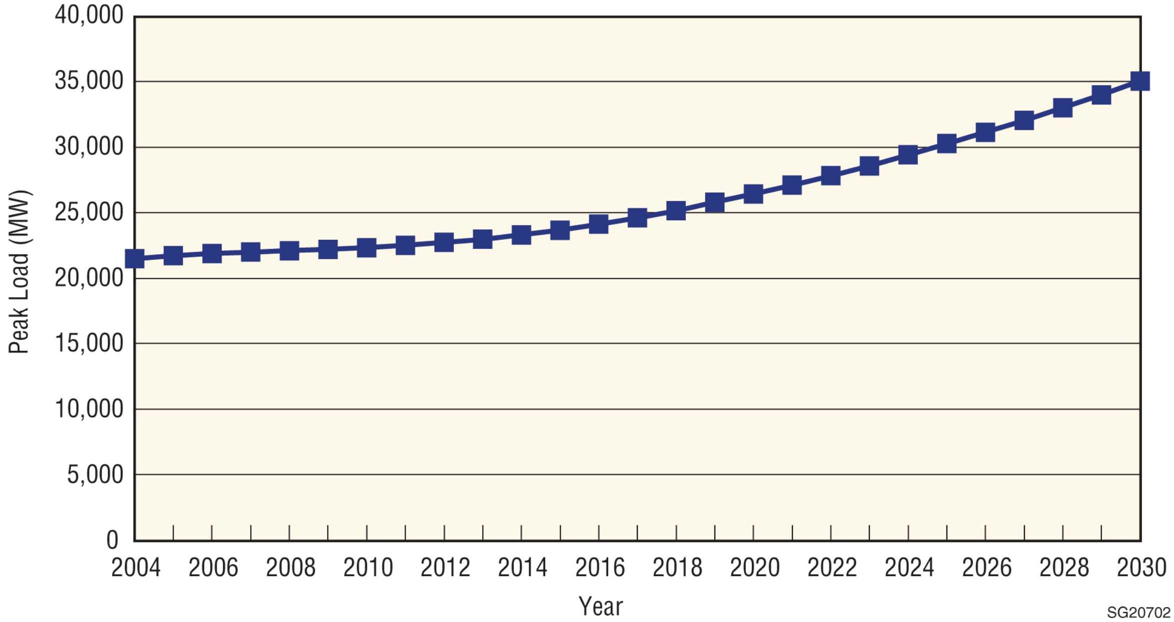

FIGURE 2 Load Forecast

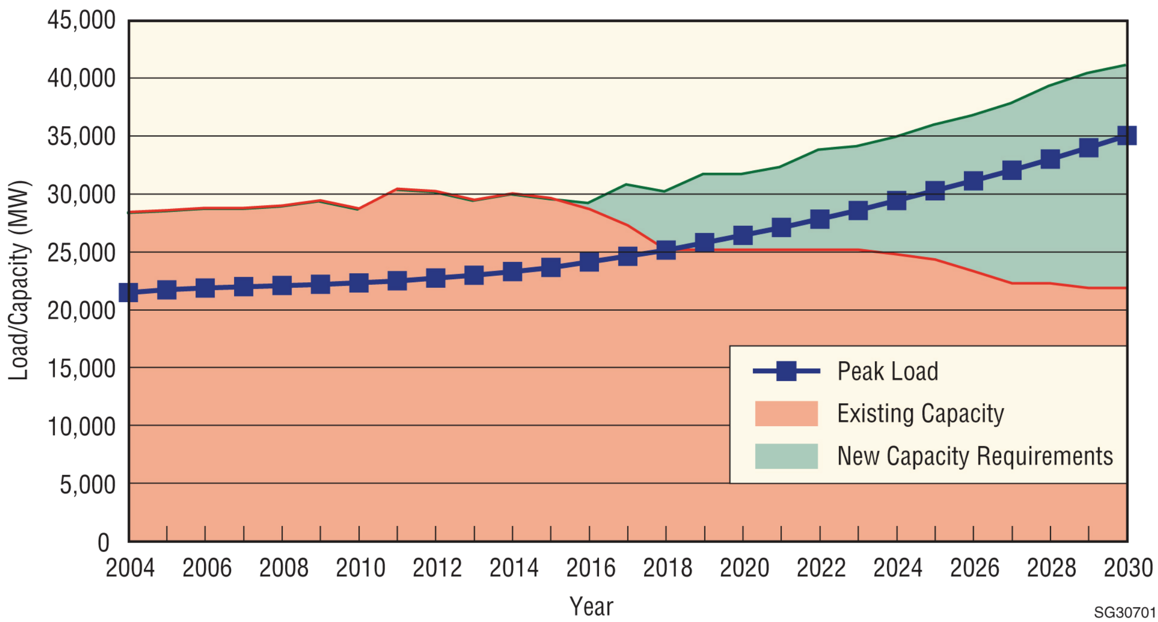

FIGURE 3 Load and Capacity Balance

14 The load forecast was provided by the Polish Energy Market Agency. The growth in load is driven by the underlying assumptions regarding macroeconomic drivers.

2. Results of the WASP Model

The model projected the appropriate mix of electricity generation covering the study period (2016–2030) for four cases:

- Base Case — 7% discount rate; $10/ton carbon tax; 1,500 MWe EPR Deployment
- Smaller Unit Case — 7% discount rate; $10/ton carbon tax; 1,000 MWe Nuclear Energy Deployment[15]
- High Discount Rate Case — 12% discount rate; $10/ton carbon tax; 1,500 MWe EPR Deployment
- Zero Carbon Tax Case — 7% discount rate; zero carbon tax; 1,500 MWe EPR Deployment

Figures 4 through 11 show the results of the model for two years of the study period: 2017 (the starting date when new nuclear capacity is projected to be economically viable for the base case) and 2030 (the end of the study period).

The study team found that a smaller-sized nuclear reactor (i.e., the 1000 MWe alternative case) has a slightly higher overnight cost than the EPR, but the savings in dispatching smaller units of base load power in the Polish grid more than counterbalances any overnight cost increases. The study team judged that significantly smaller reactors (for example, 100–500 MWe) would not be economically competitive because the significantly higher overnight costs for those smaller reactors would dominate the WASP calculation.

The four main economic drivers benefiting the deployment of new nuclear energy in the 2017 time frame are:

- Need for Poland to finalize transition to a market economy over the next decade to meet the conditions of its membership in the EU;
- Increased cost of coal-fired electricity of about 15% as a result of implementation of the Kyoto Protocol;
- Need to hedge any reliance on gas-fired electricity in light of the future supply and pricing policy of its major supplier, Gazprom; and
- Eligibility for concession loans (7% discount rate) from the European Bank for Reconstruction and Development (EBRD) because of its environmental, national security, and economic benefits.

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[15] Using a smaller nuclear plant capacity (1,000 MWe vs. 1,500 MWe) results in deploying new nuclear capacity a year earlier than the base case (i.e., 2016); based on the WASP analysis.

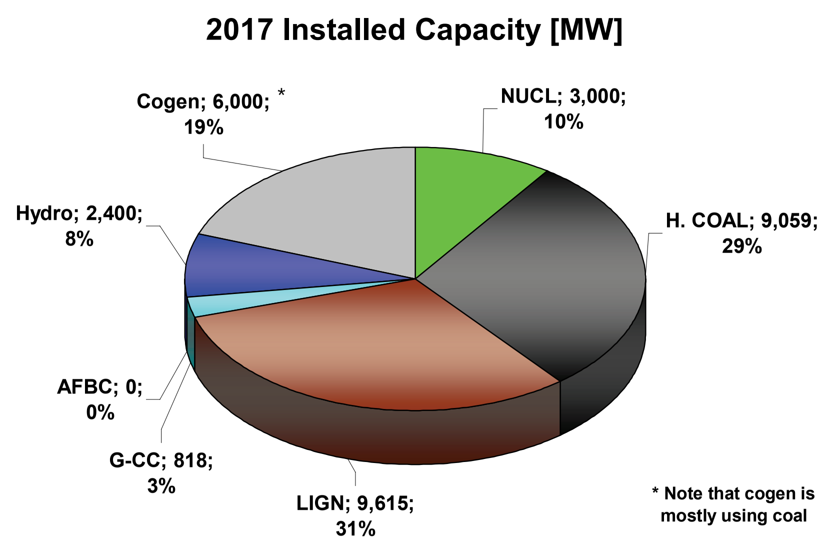

FIGURE 4 Base Case, 2017 Installed Capacity (MW)

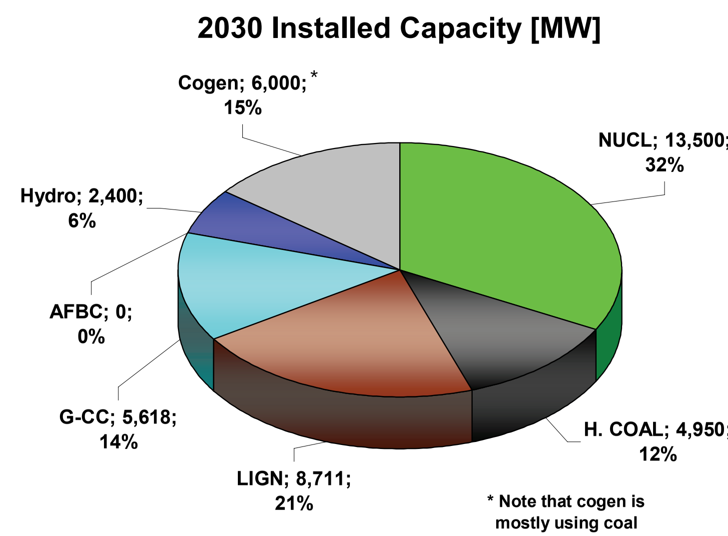

FIGURE 5 Base Case, 2030 Installed Capacity (MW)

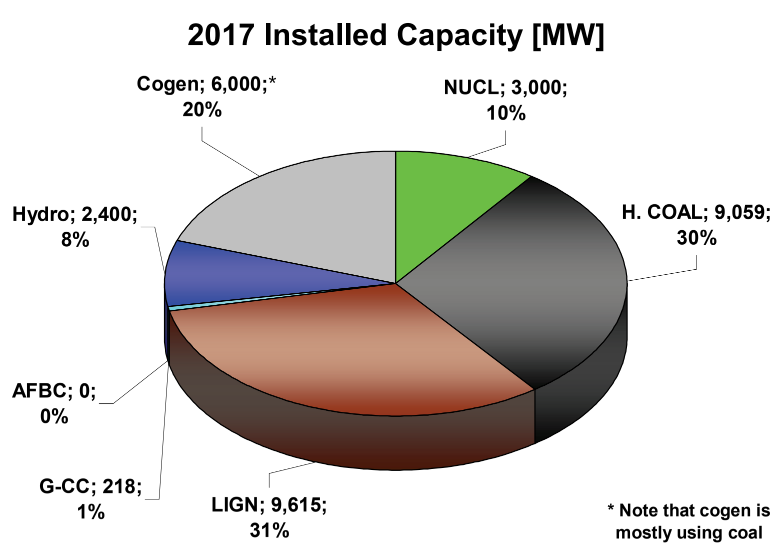

FIGURE 6 AP-1000 Case #2, 2017 Installed Capacity (MW)

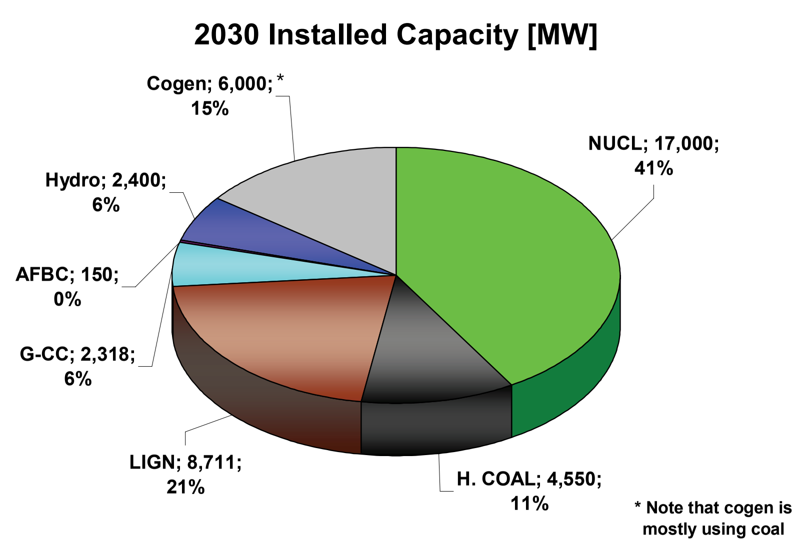

FIGURE 7 AP-1000 Case #2, 2030 Installed Capacity (MW)

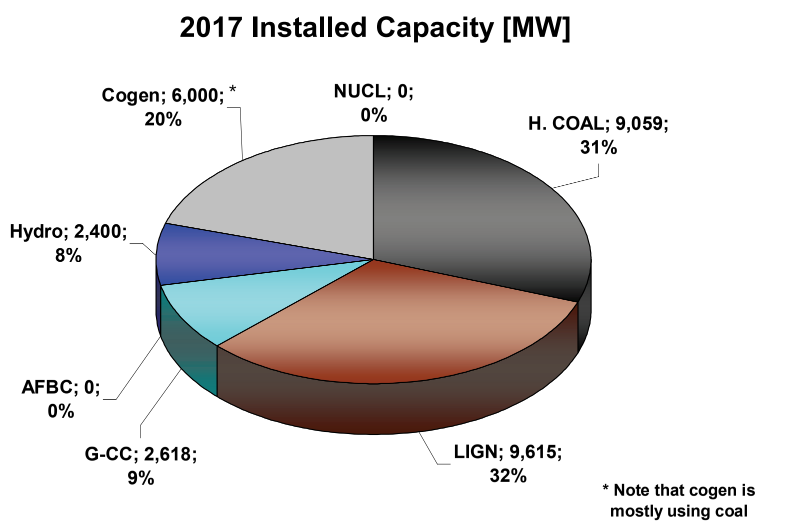

FIGURE 8 High Discount Case, 2017 Installed Capacity (MW)

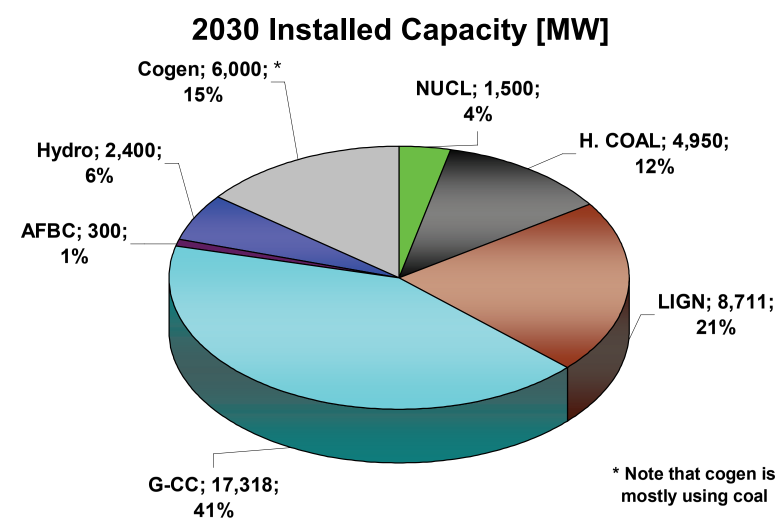

FIGURE 9 High Discount Case, 2030 Installed Capacity (MW)

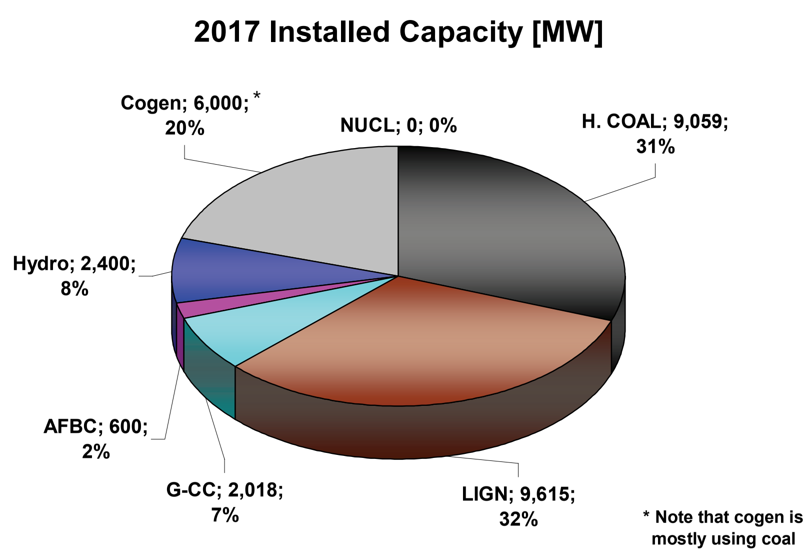

FIGURE 10 Zero Carbon Tax Case, 2017 Installed Capacity (MW)

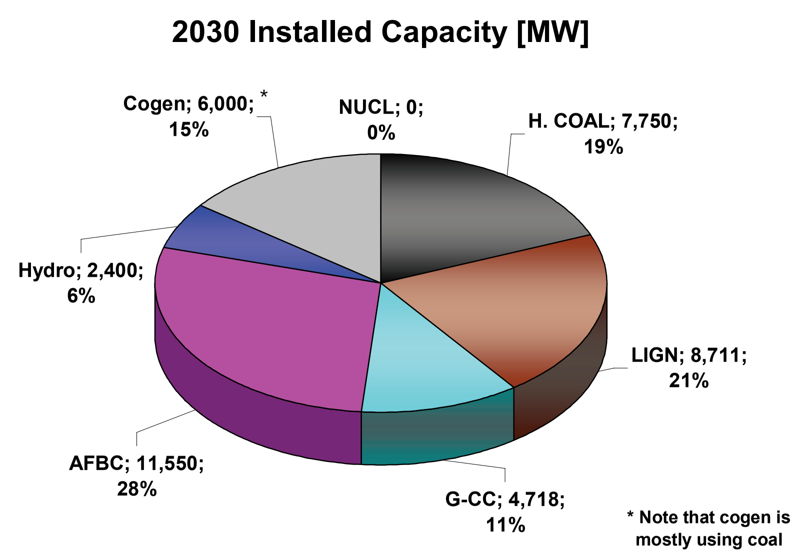

FIGURE 11 Zero Carbon Tax Case, 2030 Installed Capacity (MW)

Poland is considering a scenario of importing nuclear-generated electricity from Lithuania. If the power bridge connection between Lithuania and Poland were available as early as 2015 and about 350 MWe were available, Poland could utilize this additional capacity in this period to meet its projected demand needs.

3. Results of the EMCAS Model

The EMCAS model was developed at Argonne to analyze power systems that are in various stages of restructuring and deregulation. EMCAS employs an agent-based modeling approach and can been used as an "electronic laboratory" to probe the possible operational and economic impacts on the power system of various events. Market participants are represented as "agents" with their own set of objectives, decision-making rules, and behavioral patterns. Agents are modeled as independent entities that make decisions and take actions using limited and/or uncertain information available to them, similar to how organizations and individuals operate in the real world. EMCAS includes all the entities typically participating in power markets.

EMCAS was configured to model the Polish power grid as a set of interconnected regions or market hubs with interconnections to neighboring systems and countries. As shown in Figure 12, there are a total of five regions or zones within Poland (Northern, Western, Central, Eastern, and Southern), as well as 12 zones representing other Central European countries/regions. Each zone represents an area with corresponding electricity generation and demand, and is represented as a node in the EMCAS network. The links that connect nodes with other nodes represent the aggregate power transfer capabilities among the regions. The model was run for 2017 – the year that the WASP system expansion analysis determined as the online year for the first new nuclear units. Given the supply and demand situation, and the generation costs in each of the zones, the EMCAS model estimated zonal generations, power transfers across zones, and locational marginal prices (LMP) at each of the nodes that can be taken as a proxy for the economic strain on the grid. The results were used to identify the location in this grid configuration for the first nuclear units that would provide the largest benefit to the Polish system. Benefits were measured in terms of changes in average zonal LMPs in December 2017 with and without nuclear.

The study found that the early plants should be sited in the Northern Region of the country in the vicinity of Gdańsk[19] (benefits of $66.12/MWh) or in the Western Region of the country in the vicinity of Poznań[20] (benefits of $65.82/MWh) to address the shortage of generating capacity in those regions in Poland (Figure 13). The team also found that importing nuclear power from Lithuania would provide some economic relief (benefits of $15.54/MWh) (Figure 14).

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[19] Based on information obtained by the study team, no grid reinforcements would be needed for this site.

[20] The international press has reported that sites under consideration for a new nuclear plant include Gryfino and Klempicz near Poznań.

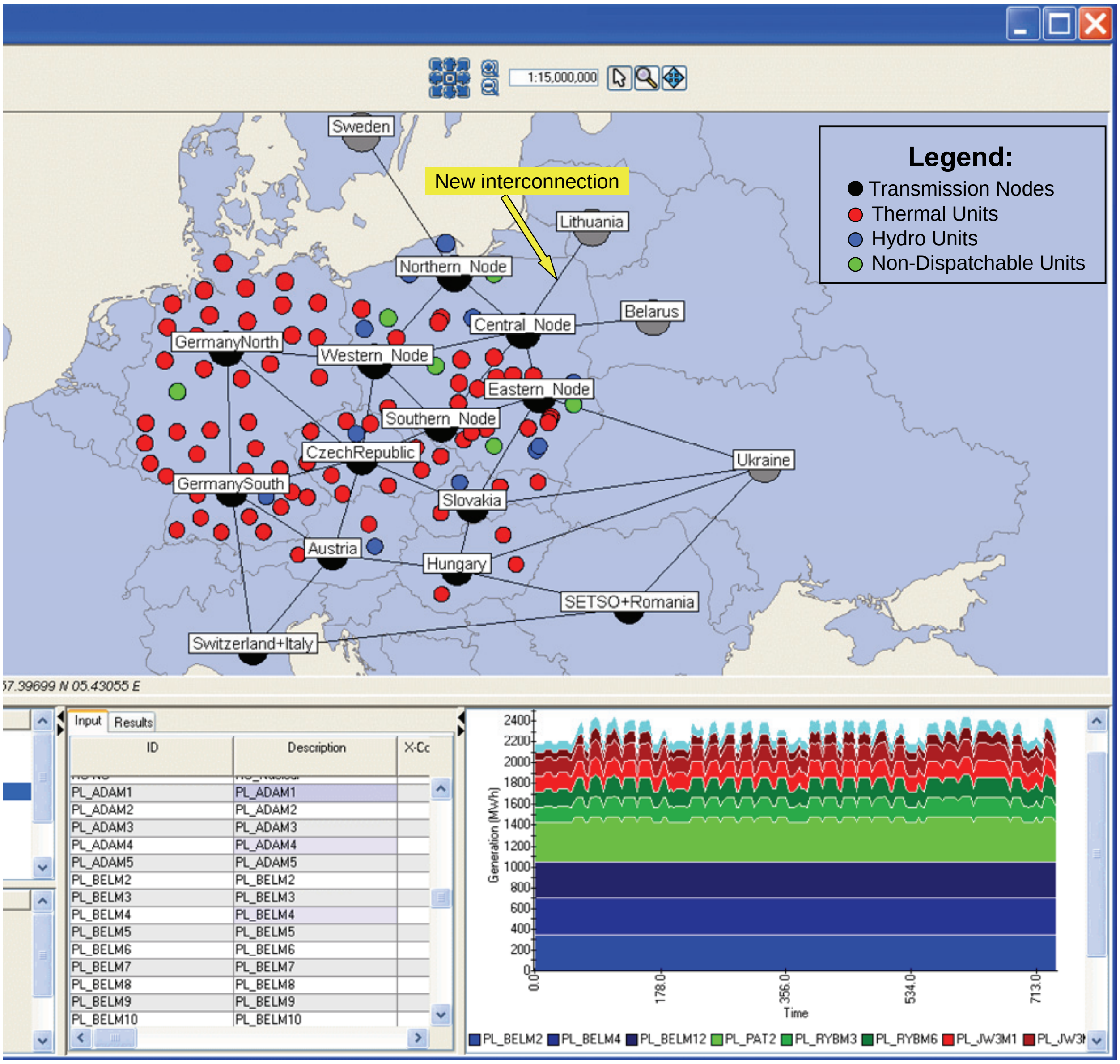

FIGURE 12 EMCAS Modeling Representation of the Polish Power Grid and Interconnections with Neighboring Systems

Base Case: No nuclear plants in the system in 2017

Alternative Cases: A total of 6 alternative cases were carried out assuming the location of new nuclear power plant in different zones/regions in Poland (North, West, Central, East, South) and in Lithuania. For the scenario analyzing possible location in Lithuania, it was also assumed that new 400-kV transmission line will be also constructed and in operation by 2017. The power transfer capability of this new transmission link, assuming a 2-circuit line, was estimated at 2,000 MW.

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